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Fujii

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(54) **WARM-UP CONTROL DEVICE FOR MACHINE TOOL**

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(52) **U.S. Cl.**
CPC ***G05B 11/01*** (2013.01); ***G05B 19/404*** (2013.01); *G05B 2219/49219* (2013.01)

(58) **Field of Classification Search**
CPC G05B 11/01; G05B 19/404; G05B 2219/49219
See application file for complete search history.

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(57) **ABSTRACT**

Prior to machining a workpiece, a warm-up control device for a machine tool is activated to perform a warm-up in which a main shaft rotary drive part and axes drive parts are driven. The amount of displacement of heat that is generated upon starting of the warm-up and changes with time is calculated every predetermined time period. Whether to end the warm-up is determined based on the thermal displacement amount. Whether to restart the warm-up after the end of the warm-up is determined based on the thermal displacement amount. When it is determined to restart the warm-up, the warm-up is restarted.

9 Claims, 11 Drawing Sheets

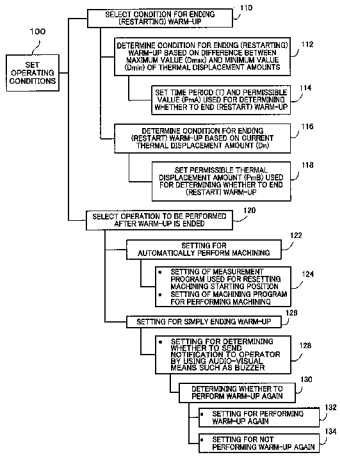

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FIG. 1

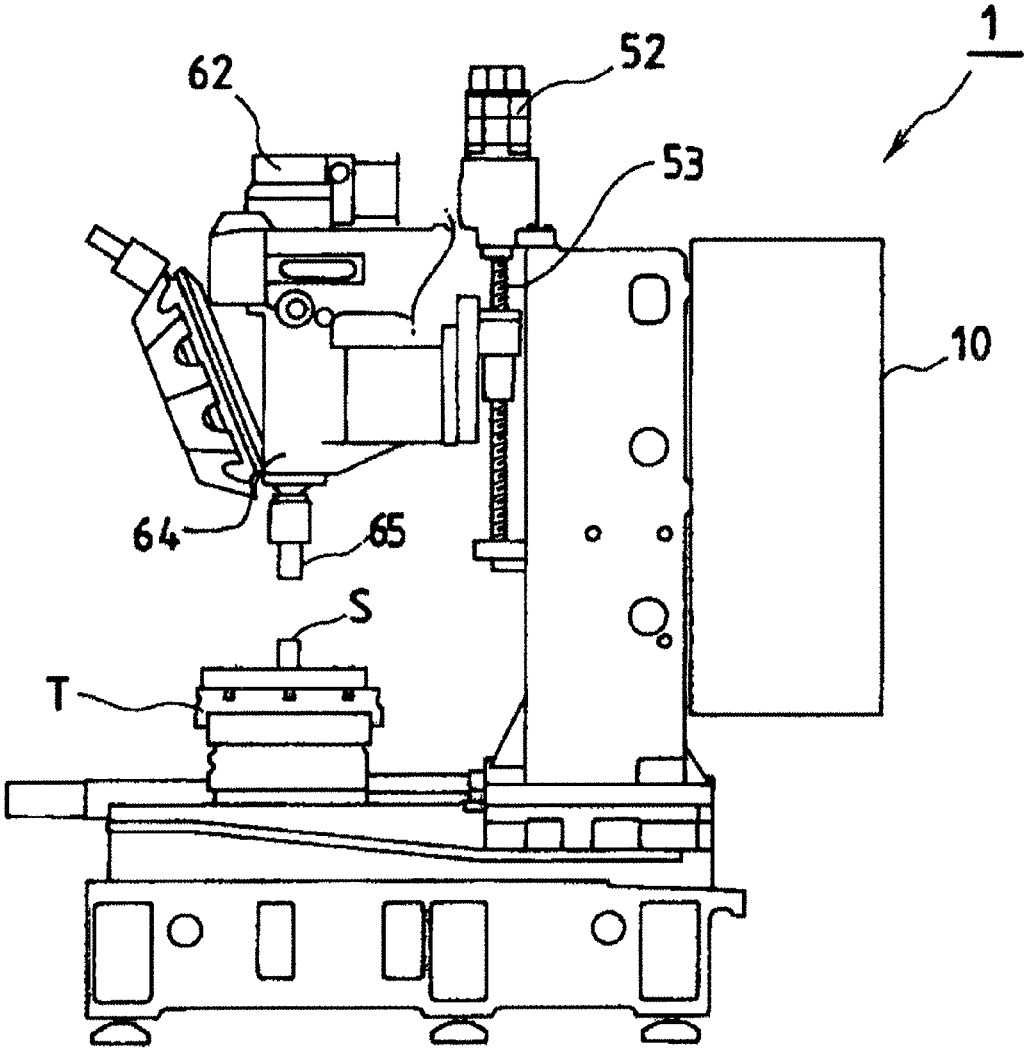


FIG. 2

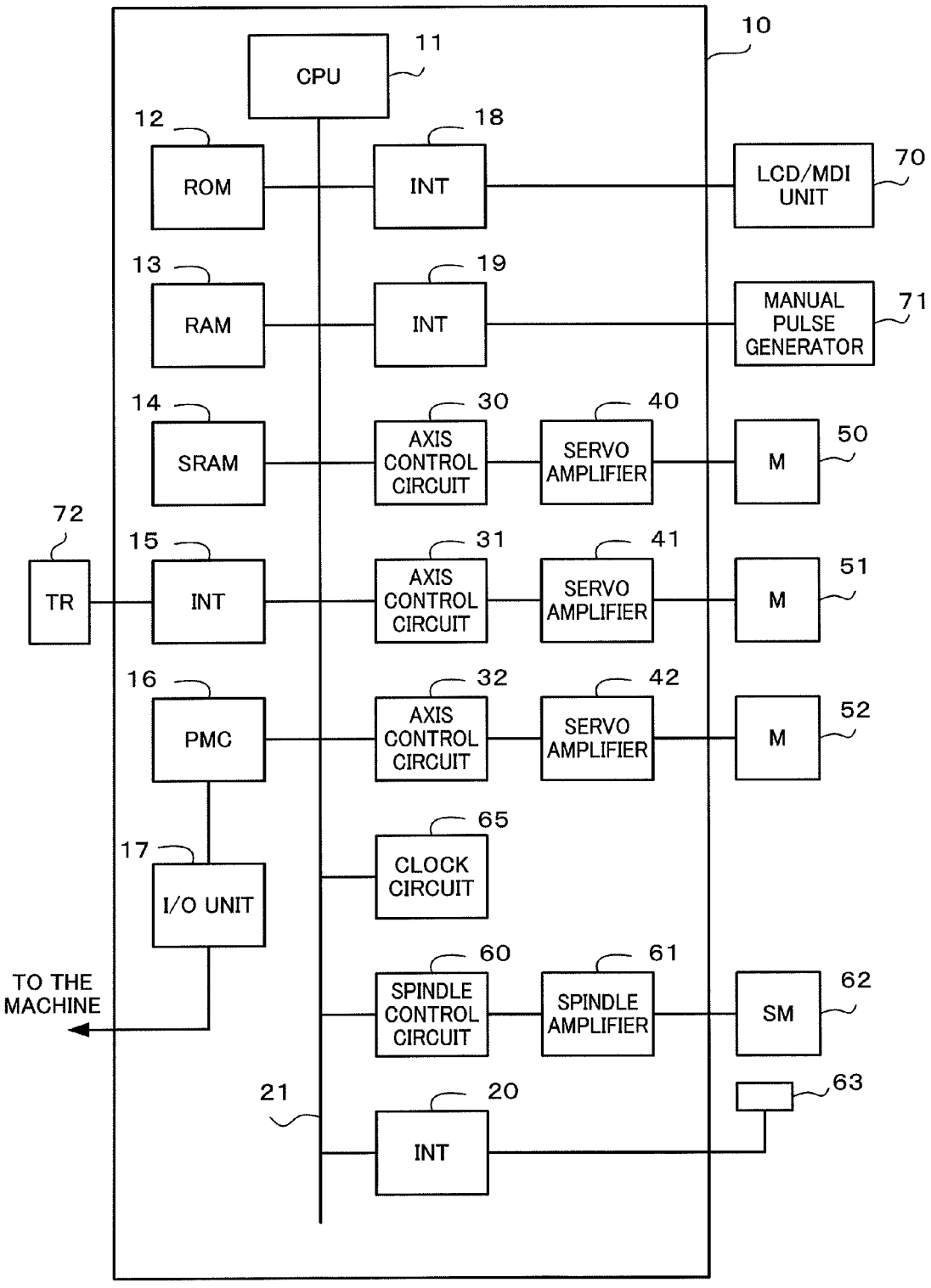

10
CPU
11
12
ROM
18
INT
LCD/MDI UNIT
70
13
RAM
19
INT
MANUAL PULSE GENERATOR
71
14
SRAM
30
AXIS CONTROL CIRCUIT
40
SERVO AMPLIFIER
M
50
72
TR
15
INT
31
AXIS CONTROL CIRCUIT
41
SERVO AMPLIFIER
M
51
16
PMC
32
AXIS CONTROL CIRCUIT
42
SERVO AMPLIFIER
M
52
65
CLOCK CIRCUIT
17
I/O UNIT
TO THE MACHINE
60
SPINDLE CONTROL CIRCUIT
61
SPINDLE AMPLIFIER
SM
62
63
21
20
INT

FIG. 3A

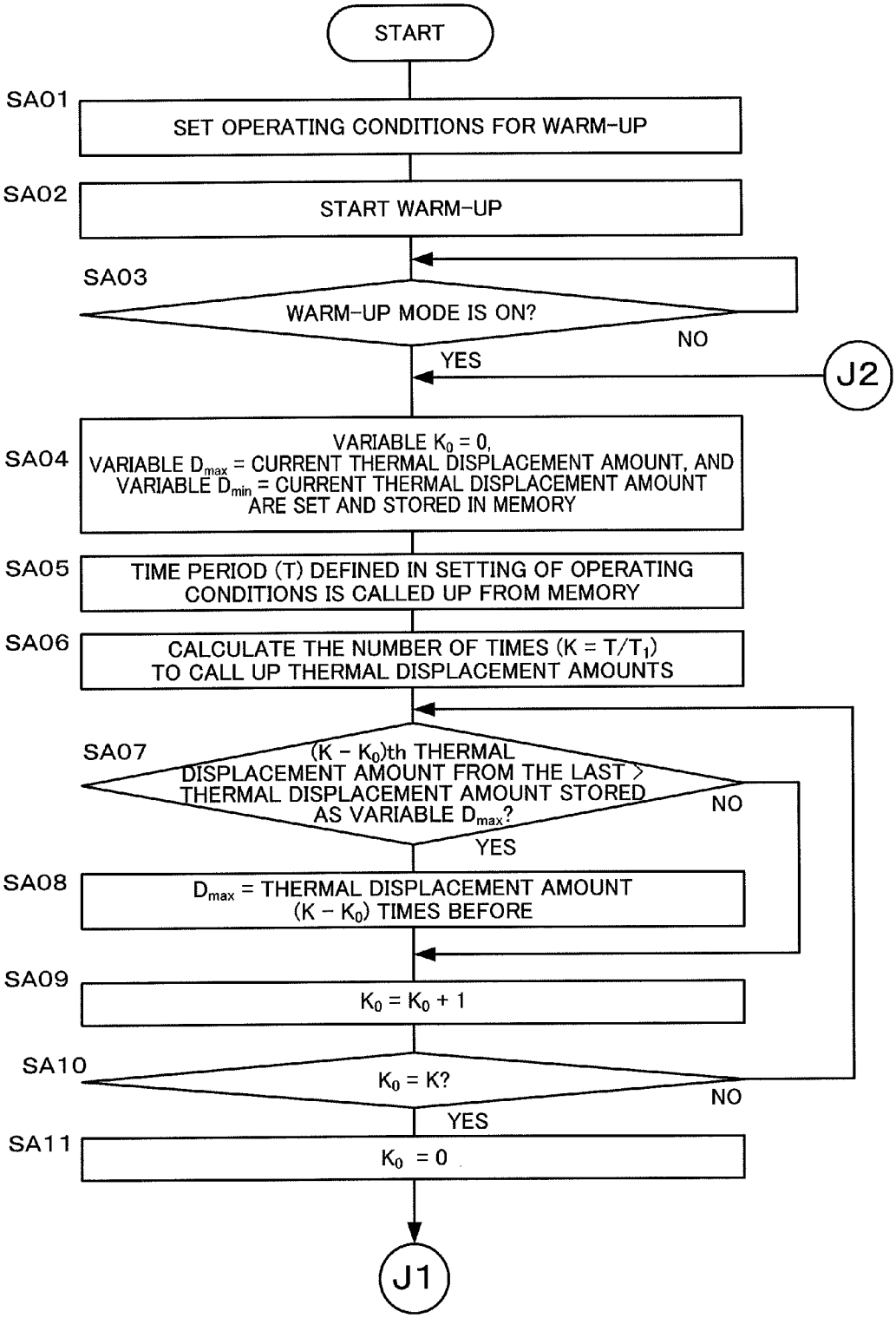

START
SA01
SET OPERATING CONDITIONS FOR WARM-UP
SA02
START WARM-UP
SA03
WARM-UP MODE IS ON?
NO
YES
J2
SA04
VARIABLE K_0 = 0,
VARIABLE D_{max} = CURRENT THERMAL DISPLACEMENT AMOUNT, AND
VARIABLE D_{min} = CURRENT THERMAL DISPLACEMENT AMOUNT
ARE SET AND STORED IN MEMORY
SA05
TIME PERIOD (T) DEFINED IN SETTING OF OPERATING CONDITIONS IS CALLED UP FROM MEMORY
SA06
CALCULATE THE NUMBER OF TIMES ($K = T/T_1$)
TO CALL UP THERMAL DISPLACEMENT AMOUNTS
SA07
($K - K_0$)th THERMAL DISPLACEMENT AMOUNT FROM THE LAST > THERMAL DISPLACEMENT AMOUNT STORED AS VARIABLE D_{max}?
NO
YES
SA08
D_{max} = THERMAL DISPLACEMENT AMOUNT ($K - K_0$) TIMES BEFORE
SA09
$K_0 = K_0 + 1$
SA10
K_0 = K?
NO
YES
SA11
K_0 = 0
J1

FIG. 3B

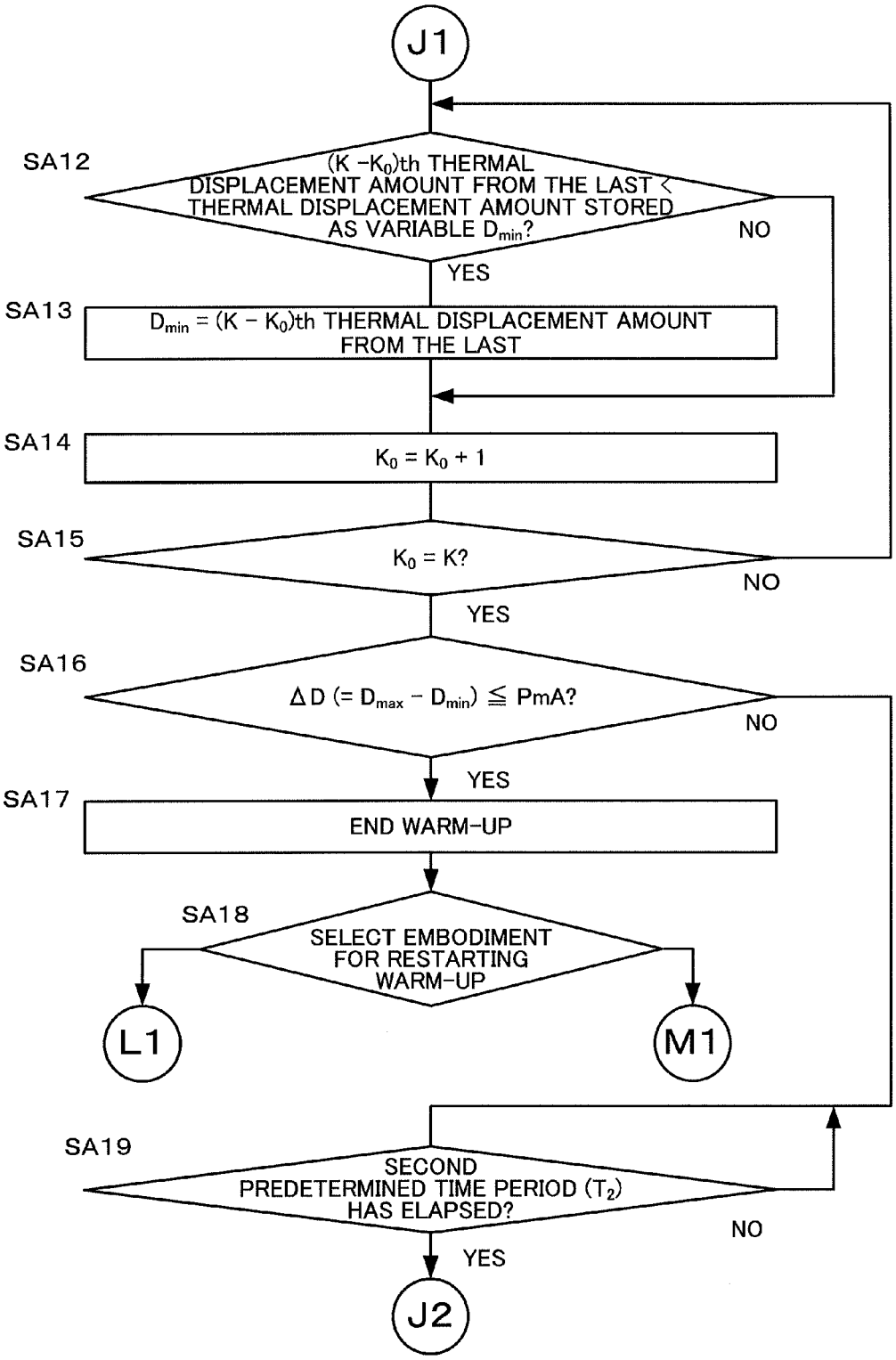

J1
SA12
(K −K0)th THERMAL DISPLACEMENT AMOUNT FROM THE LAST < THERMAL DISPLACEMENT AMOUNT STORED AS VARIABLE Dmin?
NO
YES
SA13
Dmin = (K − K0)th THERMAL DISPLACEMENT AMOUNT FROM THE LAST
SA14
K0 = K0 + 1
SA15
K0 = K?
NO
YES
SA16
ΔD (= Dmax − Dmin) ≦ PmA?
NO
YES
SA17
END WARM-UP
SA18
SELECT EMBODIMENT FOR RESTARTING WARM-UP
L1
M1
SA19
SECOND PREDETERMINED TIME PERIOD (T2) HAS ELAPSED?
NO
YES
J2

FIG. 4

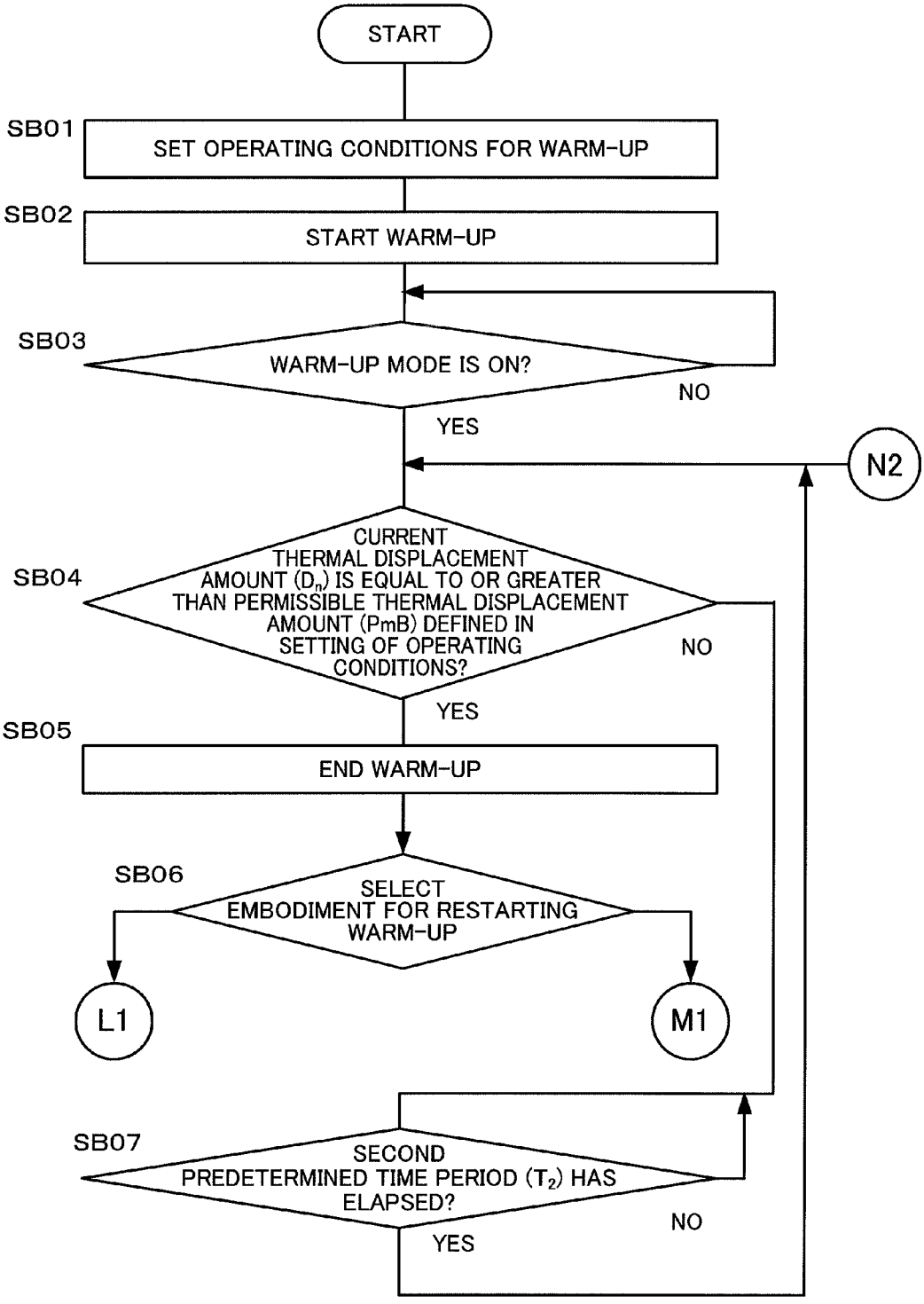

START
SB01
SET OPERATING CONDITIONS FOR WARM-UP
SB02
START WARM-UP
SB03
WARM-UP MODE IS ON?
NO
YES
N2
SB04
CURRENT THERMAL DISPLACEMENT AMOUNT (D_n) IS EQUAL TO OR GREATER THAN PERMISSIBLE THERMAL DISPLACEMENT AMOUNT (PmB) DEFINED IN SETTING OF OPERATING CONDITIONS?
NO
YES
SB05
END WARM-UP
SB06
SELECT EMBODIMENT FOR RESTARTING WARM-UP
L1
M1
SB07
SECOND PREDETERMINED TIME PERIOD (T_2) HAS ELAPSED?
NO
YES

FIG. 5A

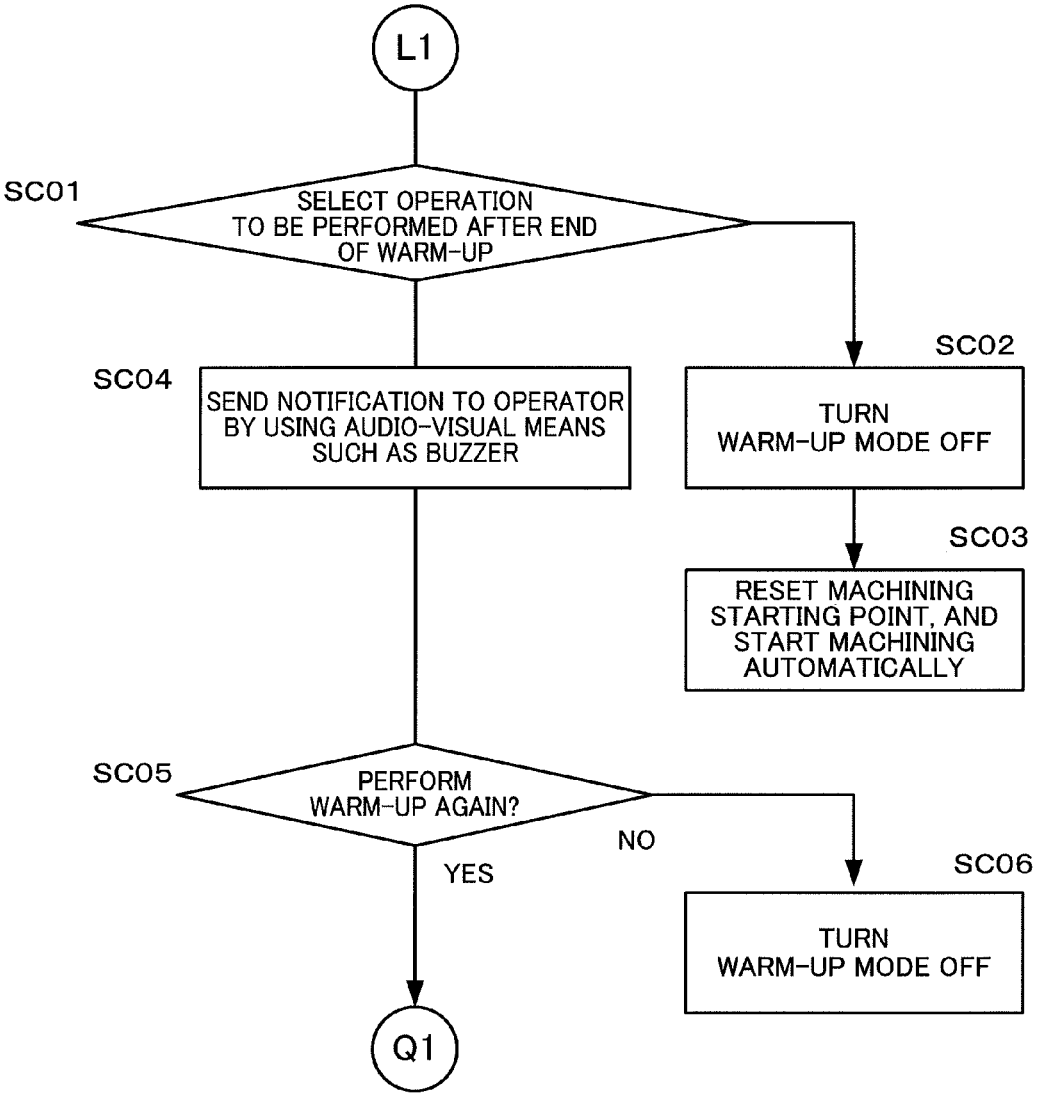

L1
SC01
SELECT OPERATION TO BE PERFORMED AFTER END OF WARM-UP
SC02
TURN WARM-UP MODE OFF
SC03
RESET MACHINING STARTING POINT, AND START MACHINING AUTOMATICALLY
SC04
SEND NOTIFICATION TO OPERATOR BY USING AUDIO-VISUAL MEANS SUCH AS BUZZER
SC05
PERFORM WARM-UP AGAIN?
NO
YES
SC06
TURN WARM-UP MODE OFF
Q1

FIG. 5B

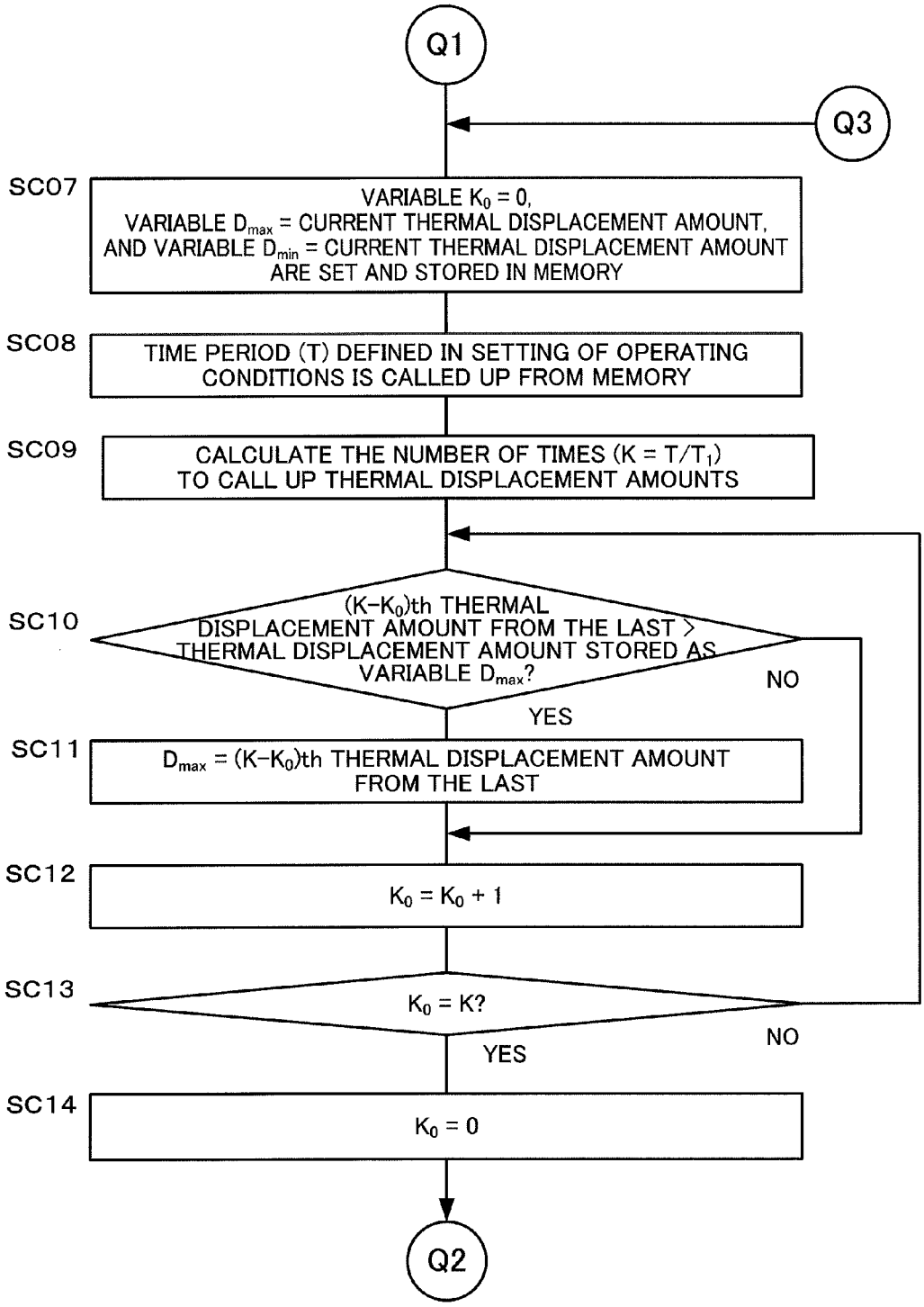

Q1
Q3
SC07
VARIABLE K_0 = 0,
VARIABLE D_{max} = CURRENT THERMAL DISPLACEMENT AMOUNT,
AND VARIABLE D_{min} = CURRENT THERMAL DISPLACEMENT AMOUNT
ARE SET AND STORED IN MEMORY
SC08
TIME PERIOD (T) DEFINED IN SETTING OF OPERATING CONDITIONS IS CALLED UP FROM MEMORY
SC09
CALCULATE THE NUMBER OF TIMES ($K = T/T_1$) TO CALL UP THERMAL DISPLACEMENT AMOUNTS
SC10
($K-K_0$)th THERMAL DISPLACEMENT AMOUNT FROM THE LAST > THERMAL DISPLACEMENT AMOUNT STORED AS VARIABLE D_{max}?
NO
YES
SC11
D_{max} = ($K-K_0$)th THERMAL DISPLACEMENT AMOUNT FROM THE LAST
SC12
$K_0 = K_0 + 1$
SC13
K_0 = K?
NO
YES
SC14
K_0 = 0
Q2

FIG. 5C

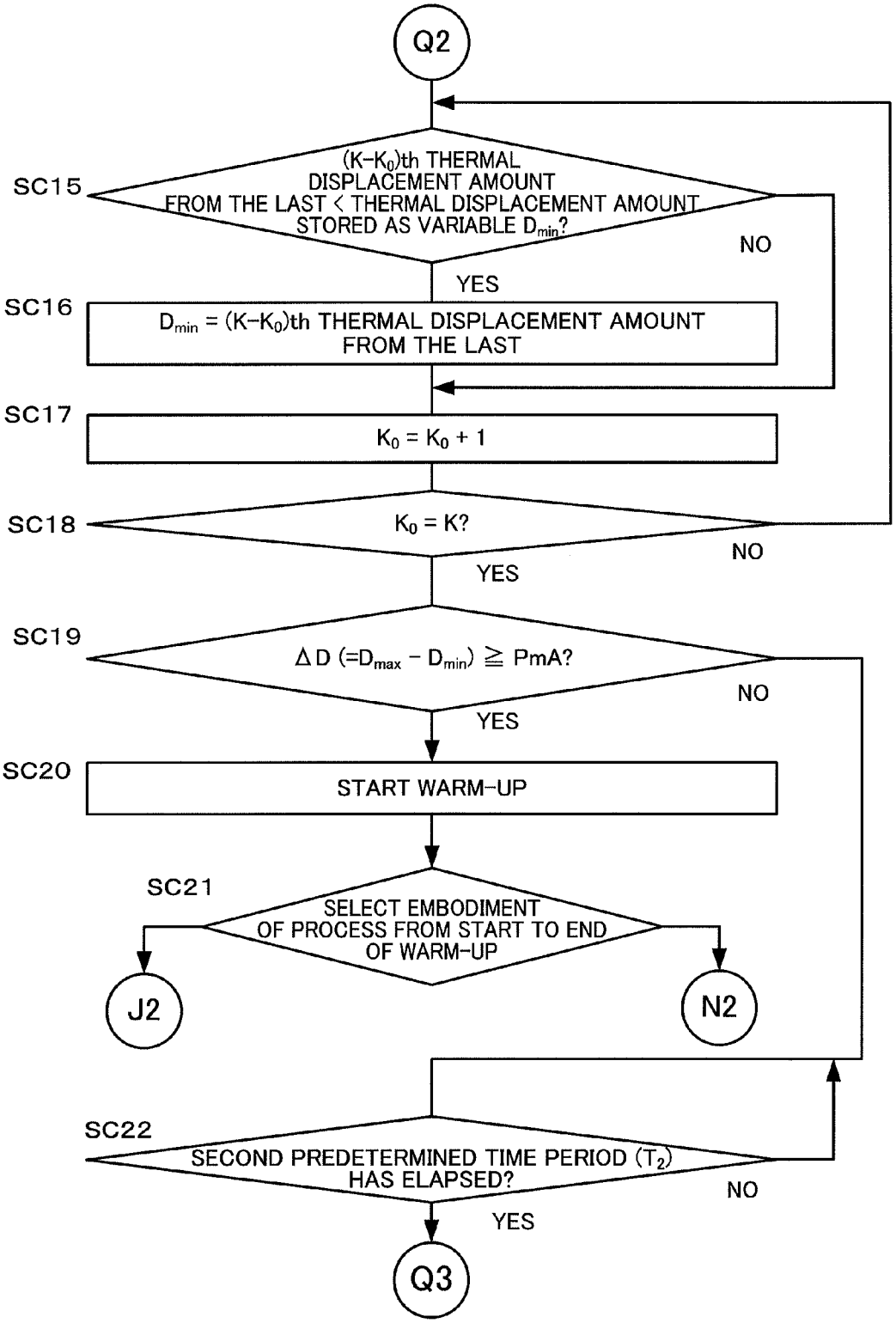

Q2
SC15
(K-K0)th THERMAL DISPLACEMENT AMOUNT FROM THE LAST < THERMAL DISPLACEMENT AMOUNT STORED AS VARIABLE Dmin?
NO
YES
SC16
Dmin = (K-K0)th THERMAL DISPLACEMENT AMOUNT FROM THE LAST
SC17
K0 = K0 + 1
SC18
K0 = K?
NO
YES
SC19
ΔD (=Dmax - Dmin) ≧ PmA?
NO
YES
SC20
START WARM-UP
SC21
SELECT EMBODIMENT OF PROCESS FROM START TO END OF WARM-UP
J2
N2
SC22
SECOND PREDETERMINED TIME PERIOD (T2) HAS ELAPSED?
NO
YES
Q3

FIG. 6

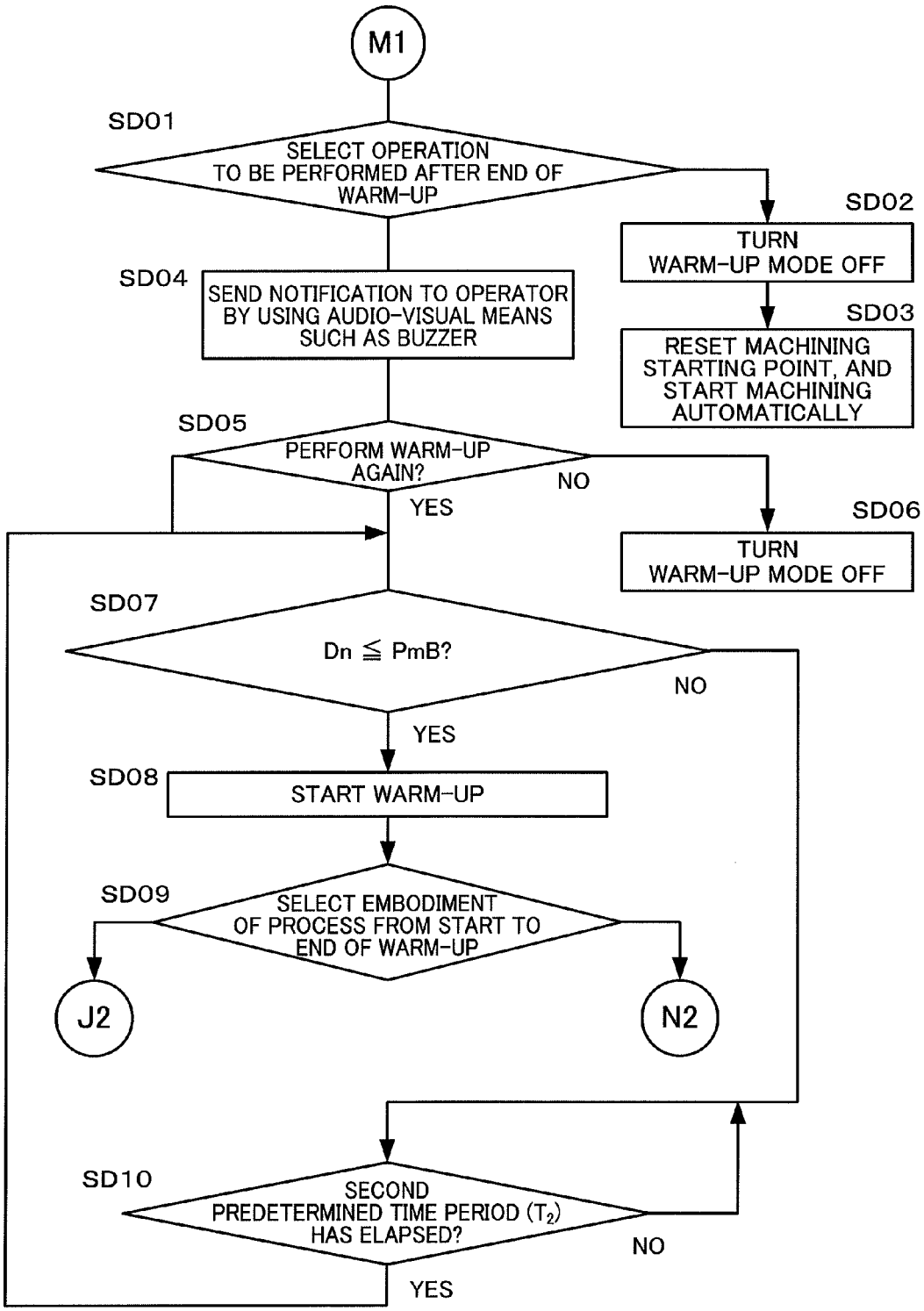

M1
SD01
SELECT OPERATION TO BE PERFORMED AFTER END OF WARM-UP
SD02
TURN WARM-UP MODE OFF
SD03
RESET MACHINING STARTING POINT, AND START MACHINING AUTOMATICALLY
SD04
SEND NOTIFICATION TO OPERATOR BY USING AUDIO-VISUAL MEANS SUCH AS BUZZER
SD05
PERFORM WARM-UP AGAIN?
NO
YES
SD06
TURN WARM-UP MODE OFF
SD07
Dn ≦ PmB?
NO
YES
SD08
START WARM-UP
SD09
SELECT EMBODIMENT OF PROCESS FROM START TO END OF WARM-UP
J2
N2
SD10
SECOND PREDETERMINED TIME PERIOD (T_2) HAS ELAPSED?
NO
YES

FIG. 7

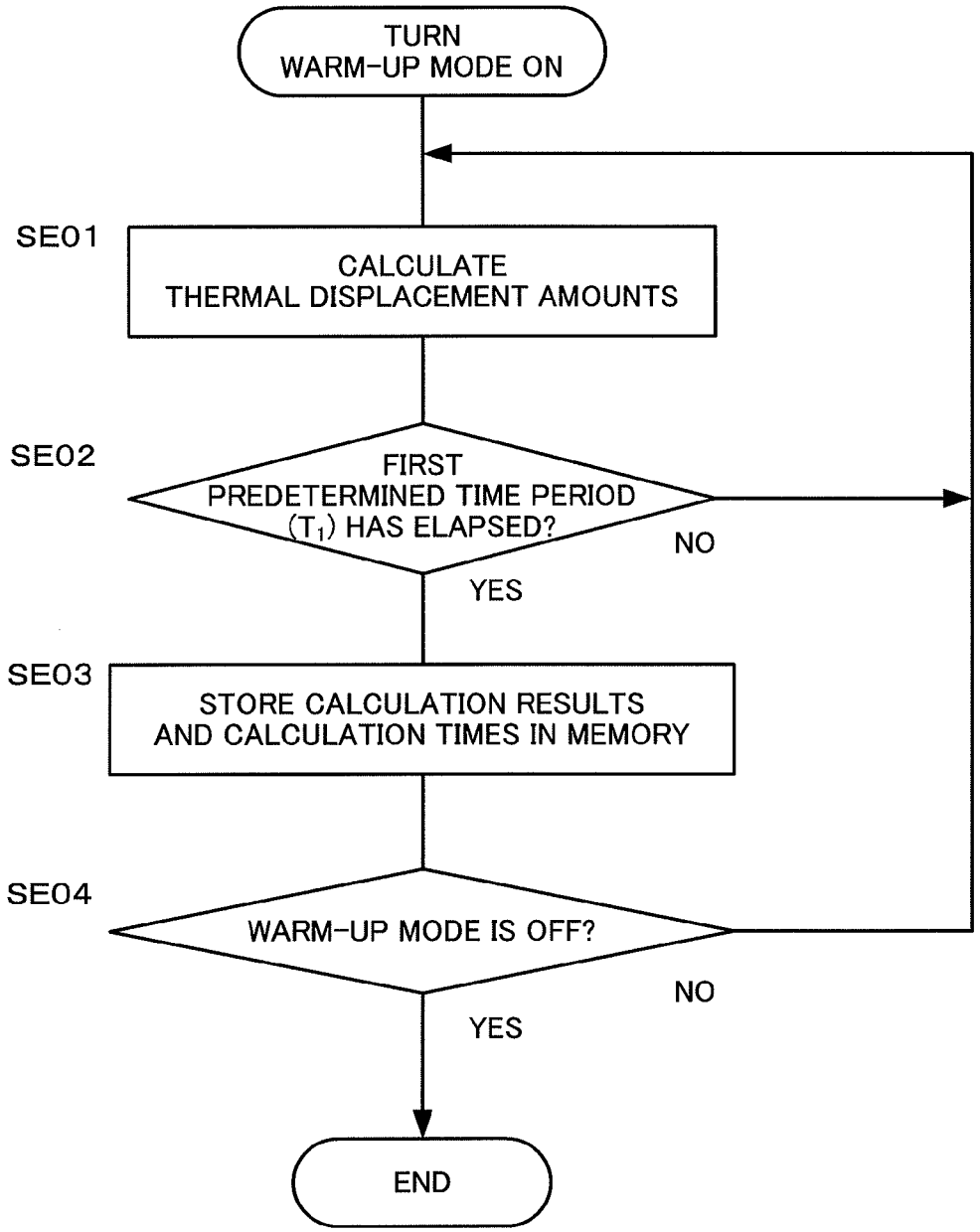
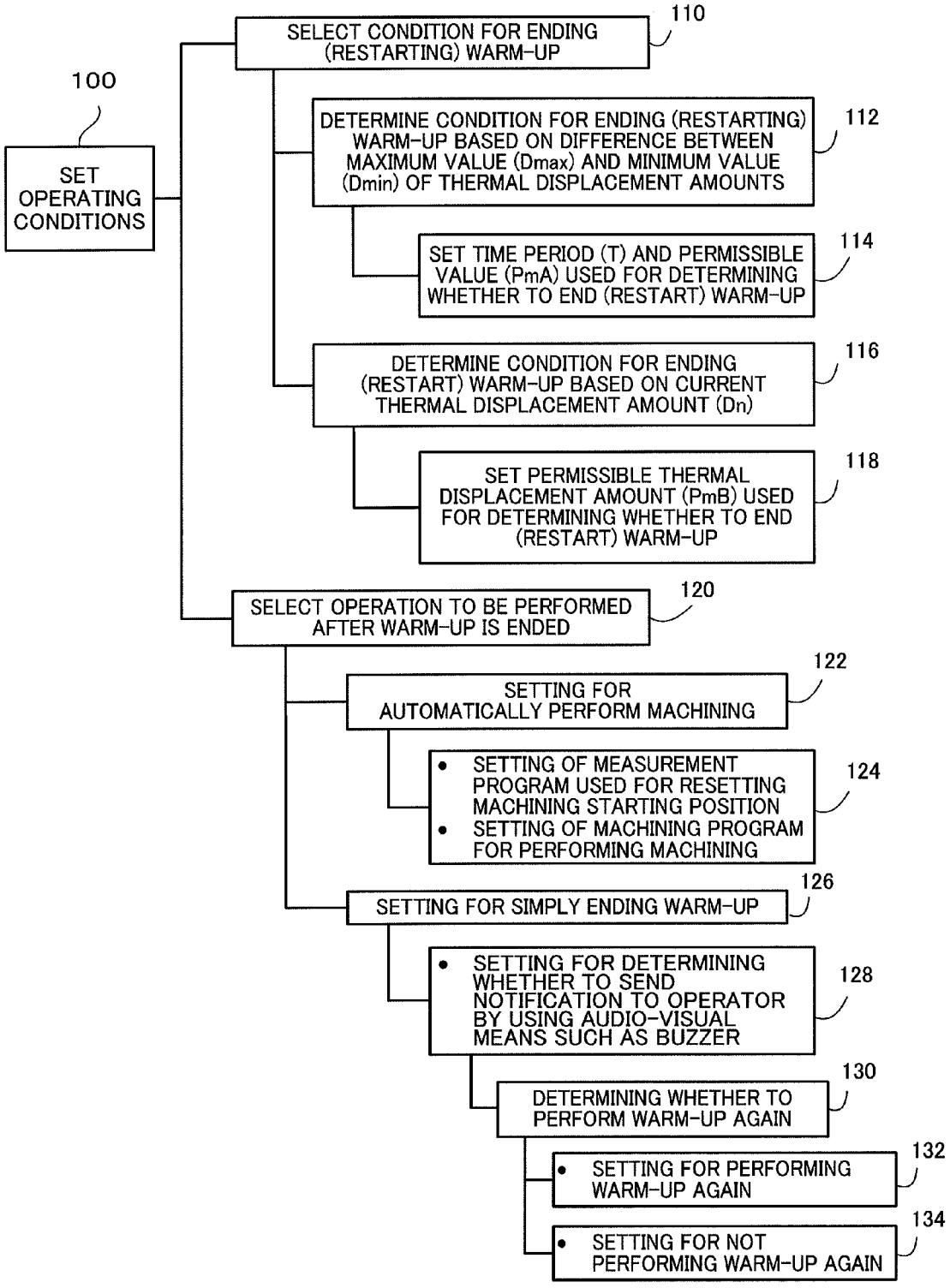

TURN
WARM-UP MODE ON
SE01
CALCULATE
THERMAL DISPLACEMENT AMOUNTS
SE02
FIRST
PREDETERMINED TIME PERIOD
(T_1) HAS ELAPSED?
NO
YES
SE03
STORE CALCULATION RESULTS
AND CALCULATION TIMES IN MEMORY
SE04
WARM-UP MODE IS OFF?
NO
YES
END

FIG. 8


100
SET OPERATING CONDITIONS
SELECT CONDITION FOR ENDING (RESTARTING) WARM-UP
110
DETERMINE CONDITION FOR ENDING (RESTARTING) WARM-UP BASED ON DIFFERENCE BETWEEN MAXIMUM VALUE (Dmax) AND MINIMUM VALUE (Dmin) OF THERMAL DISPLACEMENT AMOUNTS
112
SET TIME PERIOD (T) AND PERMISSIBLE VALUE (PmA) USED FOR DETERMINING WHETHER TO END (RESTART) WARM-UP
114
DETERMINE CONDITION FOR ENDING (RESTART) WARM-UP BASED ON CURRENT THERMAL DISPLACEMENT AMOUNT (Dn)
116
SET PERMISSIBLE THERMAL DISPLACEMENT AMOUNT (PmB) USED FOR DETERMINING WHETHER TO END (RESTART) WARM-UP
118
SELECT OPERATION TO BE PERFORMED AFTER WARM-UP IS ENDED
120
SETTING FOR AUTOMATICALLY PERFORM MACHINING
122
• SETTING OF MEASUREMENT PROGRAM USED FOR RESETTING MACHINING STARTING POSITION
• SETTING OF MACHINING PROGRAM FOR PERFORMING MACHINING
124
SETTING FOR SIMPLY ENDING WARM-UP
126
• SETTING FOR DETERMINING WHETHER TO SEND NOTIFICATION TO OPERATOR BY USING AUDIO-VISUAL MEANS SUCH AS BUZZER
128
DETERMINING WHETHER TO PERFORM WARM-UP AGAIN
130
• SETTING FOR PERFORMING WARM-UP AGAIN
132
• SETTING FOR NOT PERFORMING WARM-UP AGAIN
134

WARM-UP CONTROL DEVICE FOR MACHINE TOOL

RELATED APPLICATIONS

The present application claims priority from, Japanese Application No. 2012-028676, filed Feb. 13, 2012, the disclosure of which is hereby incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a warm-up control device for a machine tool.

2. Description of the Related Art

The main shaft attached to a machine tool is rotated by a rotary drive means such as a motor. Therefore, it is known that a machining tool attached to a tip of the main shaft is displaced by the heat generated from the rotary drive means itself or heat generated from a main shaft bearing, causing errors. Moreover, when thermal displacement occurs in a base of the machine tool due to the heat generated by drive means such as a motor used for axis feeding for relatively displacing the positions of a workpiece and the tool, changes in temperature in the environment where the machine tool is installed, and the heat generated in driving of the abovementioned main shaft, the relative position between the workpiece and the tool becomes shifted, causing machining errors.

A method called "warm-up" has been known as a way to solve these problems. A warm-up is an operating method in which, especially due to the impact of thermal displacement of the main shaft caused by its rotation, the main shaft is idled in order to maintain machining accuracy, and then a workpiece is machined after thermal displacement of the main shaft becomes stable. Although the idling for achieving stable machining accuracy is performed until the thermal displacement in the machine tool is stabilized, how long the idling needs to be performed is determined based on the experiences or intuition of a skilled operator. Thus, whether the thermal displacement is definitely stabilized or not is uncertain. Moreover, it might take an unnecessarily long time for such warm-up.

Japanese Patent Application Laid-Open No. 2009-113138, for example, discloses a method that continuously measures the position of the tip of a tool by using a measuring device such as a laser interferometer, calculates the thermal displacement amount of the position of the tip of the tool from a result of the measurement, and ends the warm-up based on the calculated thermal displacement amount.

However, Japanese Patent Application Laid-Open No. 2009-113138 only describes that the way of ending the warm-up is to simply end the warm-up or to automatically start machining. When the warm-up is simply ended, the machining starting point on the tool at which the machining is started needs to be reset manually. In a case where an operator gets caught up in another work and leaves the machine tool after the end of the warm-up, the warm-up needs to be carried out again, which is not necessarily efficient. It is not particularly problematic to start machining automatically, but automatically resetting the machining starting point requires a measuring device that is capable of controlling the tool by using a numerical controller. However, not all machine tools are equipped with such measuring devices.

SUMMARY OF THE INVENTION

The present invention was contrived in view of the problems of the conventional technologies described above, and

an object of the present invention is to provide a warm-up control device for a machine tool, which is capable of controlling an automatic restart of a warm-up after a warm-up is ended and even when an operator simply ends the warm-up and then mistakenly leaves the machine tool, and capable of preventing an unnecessary re-warm-up of the machine tool without having concern about thermal displacement that is caused when the machine tool cools down.

A warm-up control device for a machine tool according to the present invention performs, before machining a workpiece, a warm-up by driving a main shaft rotary drive part for rotating a main shaft of the machine tool and axes drive parts for relatively driving the workpiece and a tool. The warm-up control device for a machine tool has: a thermal displacement amount calculation part that obtains a thermal displacement amount that results from heat generated or released upon starting or ending the warm-up of the machine tool and changes with time; a thermal displacement amount storage unit that stores the thermal displacement amount that is calculated every predetermined time period by the thermal displacement amount calculation part; a warm-up end determination part that determines whether to end the warm-up based on the thermal displacement amount; a warm-up ending part that ends the warm-up when the warm-up end determination part determines to end the warm-up; a warm-up restart determination part that determines whether to restart the warm-up after the end of the warm-up, based on the thermal displacement amount; and a warm-up restarting part that restarts the warm-up when the warm-up restart determination part determines to restart the warm-up.

In a case where an operator is caught up in another work and mistakenly leaves the machine tool after the end of the warm-up, the present invention can eliminate the waiting time generated when restarting the warm-up, by performing control for automatically restarting the warm-up. Furthermore, because warm-up end determination means, warm-up restart determination means, and warm-up ending means can be selected in accordance with how the machine tool is used, the present invention can accommodate various environments where users use machine tools.

The thermal displacement amount storage unit may store a time at which the thermal displacement amount is calculated every predetermined time period by the thermal displacement amount calculation part, and the warm-up restart determination part may call up, from the thermal displacement amount storage unit, the thermal displacement amount that is calculated every predetermined time period back to a time traced back by a previously set time period, calculate a difference between a maximum value and minimum value out of the called thermal displacement amounts, and restart the warm-up when the difference is greater than a previously set permissible value.

According to this embodiment, in order to determine to restart the warm-up, the greatest difference between the thermal displacement amounts that are calculated every predetermined time period within a certain time range is used. Therefore, it can be accurately determined whether the stability of the thermal displacement used as the basis for determining to restart the warm-up is damaged or not. In addition, the present invention can accommodate various environments where users use machine tools, by changing a time period (T) and the permissible value (PmA) defined in "setting of operating conditions" used for the determination.

The warm-up restart determination part may restart the warm-up when a current thermal displacement amount cal-

culated by the thermal displacement amount calculation part is smaller than a previously set permissible thermal displacement amount.

According to this embodiment, in order to determine whether to restart the warm-up, a permissible thermal displacement amount (PmB), which is a fixed value that can be set freely, is used so that the value of thermal displacement determined by the operator's experiences or intuition can be reflected in controlling the restart of the warm-up.

The thermal displacement amount storage unit may store a time at which the thermal displacement amount is calculated every predetermined time period by the thermal displacement amount calculation part, and the warm-up end determination part may call up, from the thermal displacement amount storage unit, the thermal displacement amount that is calculated every predetermined time period back to a time traced back by a previously set time period, calculate a difference between a maximum value and minimum value out of the called thermal displacement amounts, and end the warm-up when the difference is smaller than a previously set permissible value.

According to this embodiment, in order to perform "determination on whether to end the warm-up," the greatest difference between the thermal displacement amounts that are calculated every predetermined time period within a certain time range is used. Therefore, it can be accurately determined whether the stability of the thermal displacement used as the basis for determining to restart the warm-up is damaged or not. In addition, the present invention can accommodate various environments where users use machine tools, by changing the time period (T) and permissible value (PmA) defined in "setting of operating conditions" used for the determination.

The warm-up end determination part may end the warm-up when a current thermal displacement amount calculated by the thermal displacement amount calculation part is greater than a previously set permissible thermal displacement amount.

According to this embodiment, in order to perform "determination on whether to end the warm-up," the permissible thermal displacement amount (PmB), which is a fixed value that can be set freely, is used so that the value of thermal displacement determined by the operator's experiences or intuition can be reflected in controlling the restart of the warm-up.

The warm-up control device for a machine tool can further have a warm-up end reporting part that sends a notification of the end of the warm-up when the warm-up is ended by the warm-up ending part.

According to this embodiment, an operation work can be performed without generating an unnecessary waiting time period, by accurately notifying an operator of the end of the warm-up. In addition, the possibility that the operator might leave the machine tool after the end of the warm-up can be reduced.

The present invention can provide a warm-up control device for a machine tool, which is capable of controlling an automatic restart of a warm-up after a warm-up is ended and even when an operator simply ends the warm-up and then mistakenly leaves the machine tool, and capable of preventing an unnecessary re-warm-up of the machine tool without having concern about thermal displacement that is caused when the machine tool cools down.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-described and other objects and characteristics of the present invention are made apparent in the descriptions of the embodiments below with reference to the attached diagrams.

FIG. **1** is a diagram showing an example of a machine tool;

FIG. **2** is a block diagram illustrating substantial parts of a numerical controller for controlling the machine tool shown in FIG. **1**;

FIGS. **3**A and **3**B are flowcharts of Embodiment 1 of a process from the start of a warm-up to the end of the warm-up, which is executed by the numerical controller shown in FIG. **2**;

FIG. **4** is a flowchart of Embodiment 2 of the process from the start of the warm-up to the end of the warm-up;

FIGS. **5**A to **5**C are flowcharts of Embodiment 1 of a process from the end of the warm-up to a restart of the warm-up;

FIG. **6** is a flowchart of Embodiment 2 of the process from the end of the warm-up to the restart of the warm-up;

FIG. **7** is a flowchart relating to calculation of a thermal displacement amount that is performed when a warm-up mode is ON; and

FIG. **8** is a diagram illustrating the items for "setting of operating conditions."

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A vertical drill press, an example of a machine tool, is now described with reference to FIG. **1**.

Reference numeral **62** represents a spindle motor, **52** a Z-axis servomotor functioning as a vertical feed shaft, **10** a numerical controller (CNC) for controlling the vertical drill press, T a table, **64** a main shaft, and **65** a tool attached to the main shaft **64**. The table T is moved in X-axis and Y-axis directions, which are perpendicular to each other in a direction perpendicular to a Z-axis, by X-axis and Y-axis servomotors, not shown. The configuration of this vertical drill press **1** is the same as those of conventional drill presses; thus, the detailed explanation thereof is omitted. In this vertical drill press, a warm-up is performed by idling the spindle motor **62**. This can stabilize the machining accuracy of the vertical drill press.

Heat that is generated from the main shaft and the amount of thermal displacement that is caused by the rotation of the spindle motor **62** can be calculated through the warm-up. For example, the thermal displacement amount in the warm-up can be calculated by previously obtaining a calculation formula for obtaining the thermal displacement amount from a rotating speed of the main shaft and a load of a main shaft motor. Note that the method disclosed in, for example, Japanese Patent Application Laid-Open No. 2002-18677 is known as a method for calculating a thermal displacement amount of a machine tool. A method for calculating the thermal displacement amount in the present invention is not limited to this known method.

Substantial parts of the numerical controller **10** shown in FIG. **1** are described using a functional block diagram of FIG. **2**.

A processor (CPU) **11** of the numerical controller **10** controls the entire numerical controller **10**. This processor **11** reads a system program stored in a ROM **12**, via a bus **21**, to control the entire numerical controller **10** in accordance with the system program. Temporary computational data or display data, as well as various data that are input by an operator via an LCD/MDI unit **70**, are stored in a RAM **13**.

An SRAM **14** is configured as a nonvolatile memory that is backed up by a battery (not shown) and keeps storing information even when the power of the numerical controller **10** is OFF. The SRAM **14** stores a program for measuring an initial position, a program for correcting thermal displacement of

the machine tool, a machining program that is read through an interface **15**, which is described hereinafter, and a machining program that is input via the LCD/MDI unit **70**. Various system programs for implementing a process of an edit mode required for creating and editing the machining programs and a process for automatically operating the machine tool, are stored in the ROM **12** in advance.

The interface **15** is an interface for connecting an external device to the numerical controller **10**. An external device **72** such as an external storage unit is connected to the numerical controller **10**. A machining program, a thermal displacement measuring program and the like are read from the external device **72**. A programmable machine controller (PMC) **16** controls auxiliary devices and the like of the machine tool based on sequence programs embedded in the numerical controller **10**. In other words, the sequence programs convert signals required by the auxiliary devices, in accordance with an M function, S function, and T function that are instructed by the machining program, and then outputs the resultant signals from an I/O unit **17** to the auxiliary devices. The auxiliary devices such as various actuators are activated by the output signals. The PMC **16** also receives signals of various switches of an operation panel disposed in a main body of the machine tool, performs necessary processes on these signals, and delivers the signals to the processor **11**.

Current positions of respective axes of the machine tool, alarms, parameters, and image signals such as image data are transmitted to the LCD/MDI unit **70** and displayed on a display of the LCD/MDI unit **70**. The LCD/MDI unit **70** is a manual data input device having the display, a keyboard, and the like. An interface **18** receives data from the keyboard of the LCD/MDI unit **70** and delivers the data to the processor **11**.

An interface **19** is connected to a manual pulse generator **71**. The manual pulse generator **71** is mounted on the operation panel of the machine tool and used for precisely determining the position of a movable part of the machine tool under axis control by a distribution pulse based on an manual operation.

X-axis and Y-axis control circuits **30** and **31** for moving the table T of the machine tool and a Z-axis control circuit **32** receive, from the processor **11**, commands for moving the axes (X, Y, and Z-axes), and output these commands to respective servo-amplifiers **40** to **42**. In response to these commands, the servo amplifiers **40** to **42** drive servomotors **50** to **52** of the axes (X, Y, and Z-axes) of the machine tool. The servomotors **50** to **52** for the respective axes have position detection encoders embedded therein. Positional signals obtained from the encoders are fed back in the form of pulse strings to the numerical controller **10**.

A spindle control circuit **60** receives a main shaft rotation command to be sent to the machine tool, and outputs a spindle speed signal to a spindle amplifier **61**. In response to the spindle speed signal, the spindle amplifier **61** rotates the spindle motor **62** of the machine tool at an instructed rotating speed, to drive the tool.

A position detector **63** is coupled to the spindle motor **62** by a gear, a belt, or the like. The position detector **63** outputs a feedback pulse in synchronization with the rotation of the main shaft. The feedback pulse is read by the processor **11** via an interface **20**. A clock circuit **65** is a timer that is adjusted to synchronize with a current time.

Control of a warm-up executed by the numerical controller **10** is described hereinafter. The numerical controller **10** functions as a warm-up control device according to the present invention.

<1> From the Start of a Warm-Up to the End of the Warm-Up (FIGS. **3**A, **3**B, and **4**)

Embodiment 1 of a process from the start of a warm-up to the end of the warm-up (FIGS. **3**A and **3**B) and Embodiment 2 of the process (FIG. **4**) are described hereinafter in detail.

Information that is required to control the warm-up is subjected to "setting of operating conditions." As shown in FIG. **8**, "setting of operating conditions" are performed as follows:

(1) Select a condition for ending (restarting) the warm-up (**110**)

(1-1) Determining a condition for ending (restarting) the warm-up, based on the difference between a maximum value (D_{max}) and minimum value (D_{min}) of thermal displacement amounts (**112**),

Setting a time period (T) and permissible value (PmA) that are used for determining whether to end (restart) the warm-up (**114**),

(1-2) Determining the condition for ending (restarting) the warm-up, based on a current thermal displacement amount (D_n) (**116**),

Setting a permissible thermal displacement amount (PmB) used for determining whether to end (restart) the warm-up (**118**),

(2) Selecting an operation to be performed subsequent to the end of the warm-up (**120**),

(2-1) Settings for automatic machining (**122**),

Settings of a measurement program used for resetting a machining starting point, and settings of the machining program for machining workpiece (**124**),

(2-2) Settings for simply ending the warm-up (**126**),

Settings for determining whether to alert the operator by using a buzzer or other audio-visual means (**128**),

Selecting whether to perform the warm-up again (**130**)

Settings for performing the warm-up again (**132**),

Settings for not performing the warm-up again (**134**).

After the warm-up is started manually, it is determined whether a warm-up mode is ON or not. When the warm-up mode is ON, "determination on whether to end the warm-up" is performed. When, on the other hand, the warm-up mode is OFF, warm-up control is not carried out. In other words, the warm-up is manually ended accordingly.

When the warm-up mode is turned ON, thermal displacement amount is calculated in the process shown in the flowchart of FIG. **7**. The thermal displacement amounts are continuously calculated as long as the warm-up mode is not turned OFF. Results of the calculation and data on calculation times are saved to the memory every first predetermined time period (T_1). The same method as the one disclosed in, for example, Japanese Patent Application Laid-Open No. 2002-18677 is used to calculate the thermal displacement amounts.

Whether to end the warm-up may be determined as follows:

(1) As a result of setting the condition for ending the warm-up, which is determined in "setting of operating conditions," each of the thermal displacement amounts stored in the memory every first predetermined time period (T_1) back to a time traced back by a time period (T) is called up from the memory, the time period (T) being set in "setting of operating conditions." Then, it is determined whether or not the difference between the maximum value (D_{max}) and the minimum value (D_{min}) of the thermal displacement amounts is smaller than the permissible value (PmA) determined in "setting of operating conditions" (see FIG. **3**A and FIG. **3**B); or

(2) It is determined whether or not the current thermal displacement amount (D_n) is greater than the permissible thermal displacement amount (PmB) determined in "setting

of operating conditions" (see FIG. **4**), depending on the condition for ending the warm-up, which is determined in "setting of operating conditions."

When "determination on whether to end the warm-up" is performed, a previous thermal displacement amount may be compared with a current thermal displacement amount every predetermined time period, and then whether the comparison result (the difference therebetween) is equal to or less than the permissible value may be determined. In this case, it can only be determined whether the thermal displacement amount is stable or not, based only on the difference between the two continuous thermal displacement amounts acquired every predetermined period. The result of such determination lacks credibility. For example, the value of the previous thermal displacement amount might be the same as the current thermal displacement amount due to the influence of false detection performed by the measuring device measuring the thermal displacement amounts. For this reason, when the thermal displacement amount is not stable as normal, it might be determined that the thermal displacement is stable.

In the embodiment where only the current thermal displacement amount is used as the basis for the determination as shown in FIG. **4**, the determination is made depending only on one thermal displacement amount in the chronological order of thermal displacement amounts. This embodiment is more unreliable than making the determination based on the difference between two thermal displacement amounts. However, because the permissible value that is used as the basis for the determination is not the difference between two thermal displacement amounts but the absolute value of a thermal displacement amount, the operator's know-how can be maximized.

The determination embodiment shown in FIGS. **3**A and **3**B designates a certain time range in the chronological order of thermal displacement amounts, calculates the maximum value and the minimum value from all of the thermal displacement amounts recorded in the range, and determines whether the difference between the maximum value and the minimum value is equal to or less than the permissible value. Thus, by designating a large time range to acquire thermal displacement amount data, a lot of thermal displacement amounts can be used as the basis for the determination. Consequently, determination accuracy of this embodiment becomes higher than those of the abovementioned two embodiments. The embodiment shown in FIGS. **3**A and **3**B sets the time period (T), which is set in "setting of operating conditions," to be the same value as the first predetermined time period (T_1) in which the thermal displacement amounts are stored (in step SA**06** shown in FIG. **3**A, which is described hereinafter, the number of times to call up the thermal displacement amounts K (=T/T_1) is 1), thereby achieving the same results as those of the embodiment where the previous thermal displacement amount is compared with the current thermal displacement amount every predetermined time period.

When it is determined in "determination on whether to end the warm-up" that the warm-up is continued, "determination on whether to end the warm-up" is repeatedly continued every second predetermined time period (T_2). When it is determined in "determination on whether to end the warm-up" that the warm-up is ended, the warm-up is ended, and an operation following the warm-up is carried out.

<2> From the End of the Warm-Up to a Restart of the Warm-Up (FIGS. **5**A to **50**, FIG. **6**)

Embodiment 1 of a process from the end of the warm-up to a restart of the warm-up (FIGS. **5**A to **5**C) and Embodiment 2 of the process (FIG. **6**) are described hereinafter in detail.

The operator is notified of the end of the warm-up by the audio-visual means such as a buzzer by selecting an operation to be performed subsequent to the end of the warm-up, the selection being performed in "setting of operating conditions." Depending on the selected operation to be performed subsequent to the end of the warm-up, the warm-up mode can automatically turned OFF, and the machining starting point can be reset and the machining itself can be started, by using the measurement program and the machining program that are set in "setting of operating conditions." When selecting to notify the operator by using the audio-visual means such as a buzzer, determination on whether to perform the warm-up again is carried out.

When selecting to perform the warm-up again based on the conditions set in "setting of operating conditions" in order to select whether to perform the warm-up again, whether to perform the warm-up again or not is determined by setting conditions for restarting the warm-up, the conditions being set in "setting of operating conditions."

Two embodiments for determining whether to restart the warm-up or not are described hereinafter.

(1) Based on the warm-up restarting conditions that are set in "setting of operating conditions," each of the thermal displacement amounts that is stored every first predetermined time period (T_1) back to a time traced back by the time period (T) is called up from the memory, the time period (T) being set in "setting of operating conditions." Then, it is determined whether to restart the warm-up, depending on whether or not the difference between the maximum value (D_{max}) and the minimum value (D_{rain}) of the thermal displacement amounts is greater than the permissible value (PmA) determined in "setting of operating conditions" (see FIGS. **5**A to **5**C).

(2) Depending on the warm-up restarting conditions that are set in "setting of operating conditions," it may be determined whether to restart the warm-up based on whether or not the current thermal displacement amount (D_n) is smaller than the permissible thermal displacement amount (PmB) set in "setting of operating conditions" (see FIG. **6**).

The embodiment ((1) described above) shown in FIGS. **5**A to **5**C for determining whether to restart the warm-up can achieve determination accuracy higher than that in the embodiment ((2) described above) shown in FIG. **6** and that in the embodiment where the previous thermal displacement amount is compared with the current thermal displacement amount every predetermined time period.

The embodiment shown in FIGS. **5**A to **5**C sets the time period (T), which is set in "setting of operating conditions," to be the same value as the first predetermined time period (T_1) in which the thermal displacement amount is stored, thereby achieving the same results as those of the embodiment where the previous thermal displacement amount is compared with the current thermal displacement amount every predetermined time period. When it is determined, in determination on whether to restart the warm-up, that warm-up is not restarted, determination on whether to restart the warm-up is repeatedly continued every second predetermined time period (T_2). When it is determined, in determination on whether to restart the warm-up, that the warm-up is restarted, the warm-up is started automatically, and "determination on whether to end the warm-up" described above is carried out.

Steps of the flowchart shown in FIGS. **3**A to **7** are now described. In order to control the warm-up, whether to perform Embodiment 1 (FIGS. **3**A and **3**B) and Embodiment 2 (FIG. **4**) of <1> describing the flow between the start of a warm-up and the end of the warm-up or Embodiment 1 (FIGS. **5**A to **5**C) and Embodiment 2 (FIG. **6**) of <2> describ-

ing the flow between the end of the warm-up and a restart of the warm-up, is set previously or set through step SA**01** (FIG. **3**A) and step SB**01** (FIG. **4**).

Embodiment 1 of the process from the start of a warm-up to the end of the warm-up is described with reference to the flowcharts shown in FIGS. **3**A and **3**B. Each of the steps of these flowcharts is described hereinafter.

[Step SA**01**] Warm-up operating conditions are set. In other words, the operating conditions stored in the memory are read in a manner illustrated in FIG. **8**.

[Step SA**02**] A warm-up is started.

[Step SA**03**] It is determined whether the warm-up mode is ON or not. When the warm-up mode is ON, the process proceeds to step SA**04**. When the warm-up mode is not ON, this step (determination) is continued until the warm-up mode is turned ON. When the warm-up mode is OFF, the warm-up can be manually ended at appropriate time without controlling the warm-up.

[Step SA**04**] Variable K_0=0, variable D_{max}=current thermal displacement amount, and variable D_{min}=current thermal displacement amount, are set and stored in the memory.

[Step SA**05**] The time period (T) that is set in "setting of operating conditions" (FIG. **8**) is called up from the memory.

[Step SA**06**] The number of times to call up the thermal displacement amounts ($K=T/T_1$) is calculated. In this case, the value T_1 is "the first predetermined time period" used in the process shown in the flowchart of FIG. **7**.

[Step SA**07**] It is determined whether the $(K-K0)^{th}$ thermal displacement amount from the last is greater than the thermal displacement amount stored as the variable D_{max}. When the thermal displacement amount is greater than the stored thermal displacement amount (YES), the process proceeds to step SA**08**. When the thermal displacement amount is not greater than the stored thermal displacement amount (NO), the process proceeds to step SA**09**.

[Step SA**08**] The value of the variable D_{max} is set as the $(K-K0)^{th}$ thermal displacement amount from the last. In other words, $K_0=K_0+1$ is set.

[Step SA**10**] It is determined whether the variable K_0 is equal to K. When the variable K_0 is equal to K (YES), the process proceeds to step SA**11**. When the variable K_0 is not equal to K (NO), the process returns to step SA**07**.

[Step SA**11**] Variable K_0=0 is set.

[Step SA**12**] It is determined whether the $(K-K0)^{th}$ thermal displacement amount from the last is smaller than the thermal displacement amount stored as the variable D_{min}. When the thermal displacement amount is smaller than the stored thermal displacement amount (YES), the process proceeds to step SA**13**. When the thermal displacement amount is not smaller than the stored thermal displacement amount (NO), the process proceeds to step SA**14**.

[Step SA**13**] The value of the variable D_{min} is set as the $(K-K0)^{th}$ thermal displacement amount from the last.

[Step SA**14**] The variable K_0 is updated. In other words, $K_0=K_0+1$ is set.

[Step SA**15**] It is determined whether the variable K_0 is equal to K. When the variable K_0 is equal to K (YES), the process proceeds to step SA**16**. When the variable K_0 is not equal to K (NO), the process returns to step SA**12**.

[Step SA**16**] It is determined whether a difference ΔD between the maximum value D_{max} and the minimum value D_{min} of the thermal displacement amounts is equal to or less than the permissible value (PmA) defined in "setting of operating conditions." When the difference is equal to or less than the permissible value ($\Delta D \leq PmA$, YES), the process proceeds to step SA**17**. When the difference is greater than the permissible value ($\Delta D > PmA$, NO), step SA**19** is performed.

[Step SA**17**] The warm-up is ended, and then the process proceeds to step SA**18**.

[Step SA**18**] Whether to set the embodiment of the process from the restart of the warm-up to the end of the warm-up as Embodiment 1 (L1) or Embodiment 2 (M2), is determined according to "setting of operating conditions" of the warm-up. Note that the operating conditions for the warm-up that are used as the basis for determining whether to set the embodiment as Embodiment 1 (L1) or Embodiment 2 (M2) are set previously or set using step SA**01**.

[Step SA**19**] It is determined whether the second predetermined time period (T_2) has elapsed or not. When the second predetermined time period has elapsed (YES), the process returns to step SA**04**. When the second predetermined time period has not elapsed (NO), the lapse of the second predetermined time period (T_2) is waited.

Embodiment 2 of the process from the start of the warm-up to the end of the warm-up is now described with reference to the flowchart of FIG. **4**. Each of the steps of the flowchart is described hereinafter.

[Step SB**01**] Warm-up operating conditions are set. In other words, the operating conditions stored in the memory are read in the manner illustrated in FIG. **8**.

[Step SB**02**] A warm-up is started.

[Step SB**03**] It is determined whether the warm-up mode is ON or not. When the warm-up mode is ON, the process proceeds to step SB**04**. When the warm-up mode is not ON, this step (determination) is continued until the warm-up mode is turned ON. When the warm-up mode is OFF, the warm-up can be manually ended at appropriate time without controlling the warm-up.

[Step SB**04**] It is determined whether the current thermal displacement amount (D_n) is equal to or greater than the permissible thermal displacement amount (PmB) defined in "setting of operating conditions." When the current thermal displacement amount is equal to or greater than the permissible thermal displacement amount ($D_n \geq PmB$, YES), the process proceeds to step SB**05**. When the current thermal displacement amount is less than the permissible thermal displacement amount ($D_n < PmB$, NO), the process proceeds to step SB**07**.

[Step SB**05**] The warm-up is ended, and then step SB**06** is carried out.

[Step SB**06**] Whether to set the embodiment of the process from the restart of the warm-up to the end of the warm-up as Embodiment 1 (L1) or Embodiment 2 (M2), is determined according to "setting of operating conditions" of the warm-up. Note that the operating conditions for the warm-up that are used as the basis for determining whether to set the embodiment as Embodiment 1 (L1) or Embodiment 2 (M2) are set previously or set using step SB**01**.

[Step SB**07**] It is determined whether the second predetermined time period (T_2) has elapsed or not. When the second predetermined time period has elapsed (YES), the process returns to step SB**04**. When the second predetermined time period has not elapsed (NO), the lapse of the second predetermined time period (T_2) is waited.

Embodiment 1 of the process from the end of the warm-up to a restart of the warm-up is now described with reference to the flowcharts of FIGS. **5**A to **5**C. Each of the steps of these flowcharts is described hereinafter.

[Step SC**01**] The operation to be performed subsequent to the end of the warm-up is selected. In other words, in step SA**01** or step SB**01**, the operating conditions stored in the memory are read in the manner illustrated in FIG. **8**, and the operation to be performed subsequent to the end of the warm-up is selected in accordance with the read operating condi-

tions. When the content described in the reference numeral **126** of FIG. **8** (simply ending the warm-up) is set, the process proceeds to step SC**04**. When the content described in the reference numeral **122** (automatically performing the machining) is set, the process proceeds to step SC**02**.

[Step SC**02**] The warm-up mode is turned OFF.

[Step SC**03**] The machining starting point is reset, and the machining is automatically started.

[Step SC**04**] Based on the set operating conditions, the operator is alerted by the audio-visual means such as a buzzer, and then the process proceeds to step SC**05**. Step SC**05** is performed even when the alert is not given.

[Step SC**05**] It is determined whether the warm-up is performed again or not. When the warm-up is performed again (YES), the process proceeds to step SC**07**. When the warm-up is not performed again (NO), the process proceeds to step SC**06**.

[Step SC**06**] The warm-up mode is turned OFF.

[Step SC**07**] Variable K_0=0, variable D_{max}=current thermal displacement amount, and variable D_{min}=current thermal displacement amount, are set and stored in the memory.

[Step SC**08**] The time period (T) that is defined in "setting of operating conditions" is called up from the memory.

[Step SC**09**] The number of times to call up the thermal displacement amounts ($K=T/T_1$) is calculated. In this case, the value T_1 is "the first predetermined time period" used in the process shown in the flowchart of FIG. **7**.

[Step SC**10**] It is determined whether the $(K-K0)^{th}$ thermal displacement amount from the last is greater than the thermal displacement amount stored as the variable D_{max}. When the thermal displacement amount is greater than the stored thermal displacement amount (YES), the process proceeds to step SC**11**. When the thermal displacement amount is not greater than the stored thermal displacement amount (NO), the process proceeds to step SC**12**.

[Step SC**11**] The value of the variable D_{max} is set as the $(K-K0)^{th}$ thermal displacement amount from the last.

[Step SC**12**] The variable K_0 is updated. In other words, $K_0=K_0+1$ is set.

[Step SC**13**] It is determined whether the variable K_0 is equal to K. When the variable K_0 is equal to K (YES), the process proceeds to step SC**14**. When the variable K_0 is not equal to K (NO), the process returns to step SC**10**.

[Step SC**14**] Variable K_0=0 is set.

[Step SC**15**] It is determined whether the $(K-K0)^{th}$ thermal displacement amount from the last is smaller than the thermal displacement amount stored as the variable D_{min}. When the thermal displacement amount is smaller than the stored thermal displacement amount (YES), the process proceeds to step SC**16**. When the thermal displacement amount is not smaller than the stored thermal displacement amount (NO), the process proceeds to step SC**17**.

[Step SC**16**] The value of the variable D_{min} is set as the $(K-K0)^{th}$ thermal displacement amount from the last.

[Step SC**17**] The variable K_0 is updated. In other words, $K_0=K_0+1$ is set.

[Step SC**18**] It is determined whether the variable K_0 is equal to K. When the variable K_0 is equal to K (YES), the process proceeds to step SC**19**. When the variable K_0 is not equal to K (NO), the process proceeds to step SC**15**.

[Step SC**19**] It is determined whether the difference ΔD between the maximum value D_{max} and the minimum value D_{min} of the thermal displacement amounts is equal to or greater than the permissible value (PmA) defined in "setting of operating conditions." When the difference is equal to or greater than the permissible value ($\Delta D \geq PmA$, YES), the process proceeds to step SC**20**. When the difference is less than the permissible value ($\Delta D < PmA$, NO), the process proceeds to step SC**22**.

[Step SC**20**] The warm-up is started, and then the process proceeds to step SC**21**.

[Step SC**21**] Whether to set the embodiment of the process from the start of the warm-up to the end of the warm-up as Embodiment 1 (J2) or Embodiment 2 (N2), is determined according to "setting of operating conditions" of the warm-up. Note that the operating conditions for the warm-up that are used as the basis for determining whether to set the embodiment as Embodiment 1 (J2) or Embodiment 2 (N2) are set previously or set using step SA**01** shown in the flowchart of FIG. **3**A or using step SB**01** shown in the flowchart of FIG. **4**.

[Step SC**22**] It is determined whether the second predetermined time period (T_2) has elapsed or not. When the second predetermined time period has elapsed (YES), the process proceeds to step SC**07**. When the second predetermined time period has not elapsed (NO), the lapse of the second predetermined time period (T_2) is waited.

Embodiment 2 of the process from the end of the warm-up to a restart of the warm-up is now described with reference to the flowchart of FIG. **6**. Each of the steps of the flowchart is described hereinafter.

[Step SD**01**] The operation to be performed subsequent to the end of the warm-up is selected. In other words, in step SA**01** or step SB**01**, the operating conditions stored in the memory are read in the manner illustrated in FIG. **8**, and the operation to be performed subsequent to the end of the warm-up is selected in accordance with the read operating conditions. When the content described in the reference numeral **126** of FIG. **8** (simply ending the warm-up) is set, the process proceeds to step SD**04**. When the content described in the reference numeral **122** (automatically performing the machining) is set, step SD**02** is performed.

[Step SD**02**] The warm-up mode is turned OFF.

[Step SD**03**] The machining starting point is reset, and the machining is automatically started.

[Step SD**04**] Based on the set operating conditions, the operator is alerted by the audio-visual means such as a buzzer, and then the process proceeds to step SD**05**. Step SD**05** is performed even when the alert is not given.

[Step SD**05**] It is determined whether the warm-up is performed again or not. When the warm-up is performed again (YES), the process proceeds to step SD**07**. When the warm-up is not performed again (NO), the process proceeds to step SD**06**.

[Step SD**06**] The warm-up mode is turned OFF.

[Step SD**07**] It is determined whether the current thermal displacement amount (D_n) is equal to or less than the permissible thermal displacement amount (PmB) defined in "setting of operating conditions." When the current thermal displacement amount is equal to or less than the permissible thermal displacement amount ($D_n \leq PmB$, YES), the process proceeds to step SD**08**. When the current thermal displacement amount is greater than the permissible thermal displacement amount ($D_n > PmB$, NO), the process proceeds to step SD**10**.

[Step SD**08**] The warm-up is started, and then the process proceeds to step SD**09**.

[Step SD**09**] Whether to set the embodiment of the process from the start of the warm-up to the end of the warm-up as Embodiment 1 (J2) or Embodiment 2 (N2), is determined according to "setting of operating conditions" of the warm-up. Note that the operating conditions for the warm-up that are used as the basis for determining whether to set the embodiment as Embodiment 1 (J2) or Embodiment 2 (N2)

are set previously or set using step SA**01** shown in the flowchart of FIG. **3**A or using step SB**01** shown in the flowchart of FIG. **4**.

[Step SD**10**] It is determined whether the second predetermined time period (T_2) has elapsed or not. When the second predetermined time period has elapsed (YES), the process proceeds to step SD**07**. When the second predetermined time period has not elapsed (NO), the lapse of the second predetermined time period is waited.

FIG. **7** is a flowchart relating to calculation of the thermal displacement amounts that is performed when the warm-up mode is ON. Each of the steps of the flowchart is described hereinafter.

[Step SE**01**] The thermal displacement amounts are calculated.

[Step SE**02**] It is determined whether the first predetermined time period (T_1) has elapsed or not. When the first predetermined time period has elapsed (YES), the process proceeds to step SE**03**. When the first predetermined period has not elapsed (NO), the process proceeds to step SE**01**.

[Step SE**03**] Results of the calculation and calculation times are stored in the memory.

[Step SE**04**] It is determined whether the warm-up mode is OFF or not. When the warm-up mode is OFF (YES), the process is ended. When the warm-up modes is not OFF (NO), the process returns to step SE**01**.

What is claimed is:

1. A warm-up control device for a machine tool, which performs, before machining a workpiece, a warm-up by driving a main shaft rotary drive part for rotating a main shaft of the machine tool and axes drive parts for relatively driving a workpiece and a tool, the warm-up control device comprising:

a thermal displacement amount calculation part that obtains a thermal displacement amount that results from heat generated or released upon starting or ending the warm-up of the machine tool and changes with time;

a thermal displacement amount storage unit that stores the thermal displacement amount that is calculated every predetermined time period by the thermal displacement amount calculation part and a time at which the thermal displacement amount is calculated;

a warm-up end determination part that determines whether to end the warm-up based on the thermal displacement amount;

a warm-up ending part that ends the warm-up when the warm-up end determination part determines to end the warm-up;

a warm-up restart determination part that calls up, from the thermal displacement amount storage unit, the thermal displacement amount that is calculated every predetermined time period back to a time traced back by a previously set time period, after the end of the warm-up, calculates a difference between a maximum value and minimum value out of the called thermal displacement amounts, and compares the difference between the maximum value and the minimum value of the displacement amounts with a previously set permissible value to determine whether or not to restart the warm-up; and

a warm-up restarting part that restarts the warm-up when the warm-up restart determination part determines to restart the warm-up.

2. The warm-up control device for a machine tool according to claim **1**, wherein the warm-up restart determination part restarts the warm-up when the difference between the maximum value and the minimum value of the displacement amounts is greater than a previously set permissible value.

3. The warm-up control device for a machine tool according to claim **2**, further comprising a warm-up end reporting part that sends a notification of the end of the warm-up when the warm-up is ended by the warm-up ending part.

4. The warm-up control device for a machine tool according to claim **1**, wherein the warm-up end determination part ends the warm-up when a current thermal displacement amount calculated by the thermal displacement amount calculation part is greater than a previously set permissible thermal displacement amount.

5. The warm-up control device for a machine tool according to claim **1**, further comprising a warm-up end reporting part that sends a notification of the end of the warm-up when the warm-up is ended by the warm-up ending part.

6. A warm-up control device for a machine tool, which performs, before machining a workpiece, a warm-up by driving a main shaft rotary drive part for rotating a main shaft of the machine tool and axes drive parts for relatively driving a workpiece and a tool, the warm-up control device comprising:

a thermal displacement amount calculation part that obtains a thermal displacement amount that results from heat generated or released upon starting or ending the warm-up of the machine tool and changes with time;

a thermal displacement amount storage unit that stores the thermal displacement amount that is calculated every predetermined time period by the thermal displacement amount calculation part and a time at which the thermal displacement amount is calculated;

a warm-up end determination part that calls up, from the thermal displacement amount storage unit, the thermal displacement amount that is calculated every predetermined time period back to a time traced back by a previously set time period, after the end of the warm-up, calculates a difference between a maximum value and minimum value out of the called thermal displacement amounts, and compares the difference between the maximum value and the minimum value of the displacement amounts with a previously set permissible value to determine whether or not to end the warm-up;

a warm-up ending part that ends the warm-up when the warm-up end determination part determines to end the warm-up;

a warm-up restart determination part that determines whether to restart the warm-up after the end of the warm-up, based on the thermal displacement amount; and

a warm-up restarting part that restarts the warm-up when the warm-up restart determination part determines to restart the warm-up.

7. The warm-up control device for a machine tool according to claim **6**, wherein the warm-up end determination part ends the warm-up when the difference is smaller than a previously set permissible value.

8. The warm-up control device for a machine tool according to claim **7**, further comprising a warm-up end reporting part that sends a notification of the end of the warm-up when the warm-up is ended by the warm-up ending part.

9. The warm-up control device for a machine tool according to claim **6**, further comprising a warm-up end reporting part that sends a notification of the end of the warm-up when the warm-up is ended by the warm-up ending part.

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